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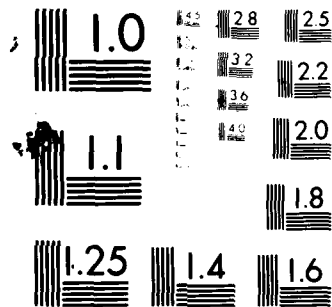
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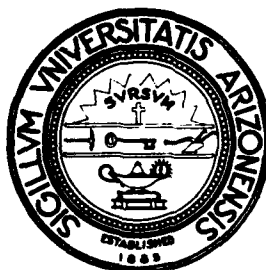
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Thematic Processes in the Comprehension of Technical Prose:

Final Report

David E. Kieras
University of Arizona



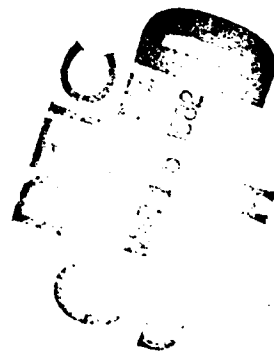
Technical Report No. (UARZ/DP/TR-82/ONR-10)
February 20, 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER No. 10 (UARZ/DP/TR-82/ONR-10)	2. GOVT ACCESSION NO. AD-A112 011	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Thematic Processes in the Comprehension of Technical Prose: Final Report		5. TYPE OF REPORT & PERIOD COVERED Final Report February 20, 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) David E. Kieras		8. CONTRACT OR GRANT NUMBER(s) N00014-78-C-0509
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology University of Arizona Tucson, AZ 85721		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N; RR 042-06 RR 042-06-02; NR 157-423
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 458) Arlington, VA 22217		12. REPORT DATE February 20, 1982
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release; Distribution Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Reading, Comprehension, Abstraction		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This final report summarizes the principal results of a project concerned with how readers identify the important content in technical prose. The theoretical framework for this process is that the important content of a passage is constructed by the reader based on the semantic content of the passage together with details of the surface structure of the passage. Thus, not only is <u>what</u> is said in the passage important, but also <u>how</u> it is said. The experimental results cover several semantic and surface		

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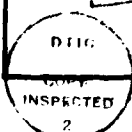
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Abstract

This final report summarizes the principal results of a project concerned with how readers identify the important content in technical prose. The theoretical framework for this process is that the important content of a passage is constructed by the reader based on the semantic content of the passage together with details of the surface structure of the passage. Thus, not only is what is said in the passage important, but also how it is said. The experimental results cover several semantic and surface structure properties that are central to the process of identifying important content, and some of the strategies that readers use. Simulation models of the comprehension and main idea identification processes were developed and tested against actual reader behavior. These models represent the general theoretical framework in a highly specific way, and thus summarize the major results of the project.

This is the final report for a project concerned with thematic processes in the comprehension of technical prose. Thematic processes are those which identify or derive the important content in a piece of prose, distinguishing it from the details or irrelevancies. Technical prose is a subtype of expository prose that is concerned with presenting information of a technical nature. The appendix in this report lists the reports, publications, and presentations resulting from the project work.

Technical prose, and expository prose in general, has not been studied by cognitive psychologists as heavily as story materials. However, understanding how people comprehend technical prose is of immense practical importance in the educational domain. Most textbooks are technical prose. They present densely packed complex information that is usually highly novel to the reader. A second area where technical prose is important is in technical documentation such as instruction or maintenance manuals. Expert opinion seems to be that technical manuals are not very comprehensible. But given the paucity of scientific knowledge about how prose of this type is understood, it is hard for any agency or manufacturer to propose, justify, or enforce substantial standards.

So the study of technical prose is extremely important for practical reasons. It is also important for scientific reasons, in that technical prose could have its own distinctive features. The function of this project was to collect a set of results on the properties of technical prose, with a focus on the thematic processes by which a reader abstracts the gist, or important content, from technical prose. The main points of these results were summarized in the form of computer simulation models which were tested against experimental data. Certain methodological problems in both the experimentation and modelling were solved in the course of the project. A more detailed and complete version of this summary can be found in Kieras (in press-a).

A Theoretical Framework

The schema theory of comprehension is currently very popular as an explanation for many of the features of prose comprehension. But as argued in Kieras (in press-a), it seems to have very little applicability to the comprehension of technical prose. A more appropriate theoretical approach would be one emphasizing those aspects of comprehension that work at the level of processing individual content facts. The best currently available theoretical framework is the macrostructure theory developed over the last decade by Kintsch and van Dijk (Kintsch, 1977; van Dijk, 1977a,b, 1980; Kintsch & van Dijk, 1978). This framework, with some modifications, was used in the project.

The macrostructure theory can be summarized in its main content very briefly: When a reader comprehends a passage, he or she first extracts the microstructure of the passage, and then applies macro-rules to derive a passage macrostructure. The

microstructure represents the immediate content of the passage, while the macrostructure represents the gist, or important content, of the passage. The macrorules essentially "boil down" the large number of micropropositions to the relatively small number of macropropositions. The macrostructure propositions are then given priority for storage in memory. Upon recall, the macropropositions are expanded to produce a paraphrased, and possibly distorted, version of the original passage.

In terms of the macrostructure theory, the process of abstracting the thematic content is the process of building the passage macrostructure. However, to address this process more directly, it is necessary to modify the macrostructure framework, because the goal of the Kintsch and van Dijk work has been on explaining the properties of prose recall, and not explicating the process by which the macrostructure is built. As a result, the macrostructure building process has been studied only indirectly, with the mechanisms of memory storage and retrieval intervening. Also, the macro-rules as defined thus far have not been worked out in any detail, and, more importantly, the macro-rules operate only on the semantic, or propositional, content of the passage. Other influences, such as the textual surface structure, on the macrostructure-building process need to be included.

The framework proposed here is that the macrostructure-building process uses the propositional content of the passage primarily, but is guided by the passage surface structure. In particular, there seem to be common text grammars which specify where in the passage important information is likely to appear, and there are several surface-level signals that mark individual items of information that are important to the passage macrostructure. Thus, abstracting the main content from a passage depends not only on the semantic content of what is said, but also on the specifics of how it is said, both at the level of the whole passage, and at the level of individual sentences. Results will be summarized below that support this point of view, followed by a brief description of a simulation model that illustrates this view of the macrostructure-building process.

Methods for Studying Thematic Processes

The results summarized below concern how subjects identify the main content of a passage. They were obtained by using an experimental task that is substantially different from the usual recall task. The subject is given a paragraph-length passage to read, and then is asked to provide a statement of the important content of the passage. This is either a statement of the main item, which is required to be a title-like noun phrase that indicates what the passage is about, or a statement of the main idea, which is a brief complete sentence that states the point, or main idea, of the passage.

The main idea or main item responses can be analyzed for content, and then examined to determine what content of the passage is being used to produce the response. A simple way to

analyze the response content is to sort the responses into rough categories. If this is done blind to a within-passage manipulation, the results will be reasonably reliable. However, there is no way to compare responses obtained for completely different passages with this simple method, since the grain of the categories can not be controlled. A more detailed approach, based on a propositional analysis of the responses, is described in Bovair and Kieras (Note 1).

Reading times for the entire passage, or its individual sentences, can be collected and related to the passage structure and content of the responses. Reading times can reveal changes in the amount of macroprocessing required by a passage as a function of manipulations in the form or content of the passage. By using a sentence-at-a-time procedure, considerable detail can be obtained about effects of passage manipulations on reading time.

A final measure used in the project work is importance ratings. Subjects engage in a main idea response task, but in addition, they rate the individual passage sentences for importance to the main idea. This can be done either with the entire passage present, or in a sentence-at-a-time paradigm.

Results

Properties of Macrostructure

The relation of main items and main ideas. Theoretically, the main item is simply the most important referent in the passage, whereas the main idea is the most important proposition. Presumably, there should be an intimate relationship between these two response forms. In Kieras (Note 2) subjects generated either main idea or main item responses for paragraphs taken from Scientific American articles. One way the two response types were related was that popular main items were also popular surface subjects of main idea responses, corresponding to the theoretical intuition that main ideas are about main items. A second result was that producing the main item of a passage is much easier than producing the main idea. The average completion time per paragraph for the main idea task was about 40 seconds longer than for the main item task. While subjects had to write more in the main idea task, it seems unlikely that this large amount of time was required simply to write a sentence as opposed to a noun phrase. Rather, the additional time must reflect a substantial difference in the processes involved. Identifying the main referent involves simply singling out the main argument of the mass of propositions, whereas finding the main proposition would require finding the set of arguments that is most important, and then picking the most important relation connecting them. A similar idea at a simpler level appears in the results of Manelis (1980) and Kieras (1978), which suggest that in simple passages thematic content responses may be determined by which proposition is "central" in the passage structure.

Global coherence. One of the defining features of a well-formed passage is global coherence, the property of the passage being about one thing (van Dijk, 1979, 1980). Kieras (1981a) found that subjects could generate main item statements for passages that had a single major referent much faster and more consistently than for passages that had three major referents. While this is a simple result, examination of the content of the responses showed that when there is a single major referent, subjects show a strong tendency to simply report it as the main item. But when there is more than one major referent, many readers infer another referent that subsumes the three that were presented in the passage. Thus readers can arrive at a global topic even though the passage does not have an obvious explicit one. This extra macro-level processing takes additional time, and its dependence on an individual reader's idiosyncratic inferences results in less consistency between subjects.

Different types of macrostructure. Passages differ in the relationship of their macrostructure to the microstructure. This issue is best illustrated by referring to the rules that van Dijk (1977a,b, 1980) proposed for the construction of macrostructure. The two most important rules are (1) Generalization: A set of propositions consisting of instances of a single general concept can be replaced by the single general proposition; (2) Construction-Integration: A series of propositions can be replaced by their consequence. For example, a passage describing the history of the Watergate affair can be summarized by the statement Nixon resigned because of Watergate.

Kieras (Note 3) examined several passages whose main ideas were based on either the generalization rule or the construction-integration rule. The conclusion was that subjects were faster, and more consistent, at producing main idea statements for the generalization passages than for the construction-integration ones. Moreover, if the main idea was explicitly stated in the passage, readers were generally faster and more consistent in their responding than if it were absent, and tended to reproduce the presented main idea in their responses. But this effect was considerably weaker in the construction-integration passages, suggesting that these macrostructures were considerably more difficult to identify than the generalization structures.

In terms of macroprocessing, in the generalization passages, the reader must simply recognize the pattern of instances of the same general concept. The macrostructure of such a passage is thus a rather simple single-layer tree. Providing the generalization explicitly almost guarantees that the pattern will be recognized. But, in the construction-integration passages, the reader must be able to deduce or recognize the chain of antecedents and consequences in the argument being presented, or the final outcome of a sequence of events. This reasoning is more complex compared to the generalization passages, and so is slower, and depends more on the idiosyncratic knowledge and reasoning process of the individual subjects, and so is less consistent.

Even an explicit main idea may not be recognized as such by all subjects.

Signals for Thematic Content

Sentence topic-comment assignment. Whether a referent appears as the surface subject of passage sentences affects its thematic importance, since this syntactic position usually carries a marking of the sentence topic. Perfetti and Goldman (1974, 1975) found that readers assign the topical referent of a passage to the surface subject position of a sentence, and will use the passive voice, if necessary, to do so. Van Dijk (1979) also pointed out that the assignment of items to either the topic or comment position in a sentence will be determined by the global topic of the passage. However, Kieras (1981a) showed that topic-comment assignment could influence main item responses by using passages in which the sentence topic-comment assignment could be reversed, while essentially preserving the propositional content. This result shows that sentence surface structure can influence the macrostructure-building process.

Weak thematic markers. If the main idea is otherwise clear, marking it may have little or no effect. Some explicit markers of thematic content are titles, which name the main item explicitly, and marking phrases, such as the important point is that..., which signal important propositions.

Effects of such markers on memory for passage content appears to be weak. By using passages with two possible global topics and manipulating the title of the passage, Schallert (1976) showed effects of titles on recognition memory, but not recall, and Kozminsky (1977) found recall effects that were fairly weak. Likewise, the reported effects of marking phrases on recall (Meyer, 1977) also appear to be weak.

These markers also appear to be weak in influencing thematic responses. In unpublished work, Kieras used passages that had already been used in main item and main idea tasks, and so a strong and a weak main idea or item could be chosen for each one. A comparison was done for both main idea and main item response tasks, using titles and marking phrases, with either no marker, marking the strong idea or item, or marking the weak item or idea. Although other effects appeared, such as the initial mention effect (see below), no effects of the marking condition on main idea or main item statements appeared at all. The conclusion is that when the thematic content is reasonably clear, the reader considers the markers as redundant, or simply ignores them.

Since the effectiveness of various forms of emphasis is an important practical question in document design (cf. Charrow & Redish, Note 4; Swarts, Flower, & Hayes, Note 5), further study of them would be worthwhile. But it could be that their effects, if any, are transient. That is, titles or marking phrases may influence which hypotheses about the main idea are considered before the final result is arrived at, but this final result may

not reflect the markers at all. Of course, if the material were almost incomprehensible, the reader might be forced to rely much more heavily on these markers. But notice that the results described above were obtained using technical passages which were in fact very unfamiliar to readers. Apparently, the semantic content of the passages was usable, in spite of its unfamiliarity, and dominated the surface-level markers. This is an instance of the principle of "shallow semantics" discussed below.

The Role of Text Structure

Location of important information. At the level of text structure the concern is where in the passage the important information appears, as opposed to the nature of the information itself. One question is whether there are standard locations for important information.

Kieras (Note 6) reported one study in which subjects produced main idea statements for naturally occurring paragraphs from Scientific American. When the content of the responses was compared to the original paragraph sentences, it appeared that when the source of the main idea could be assigned to a single sentence, this source was mostly the beginning of the passage, and to some extent, the end, forming a U-shaped function with a very high peak on the first sentence. Another study in Kieras (Note 6) had subjects underline the most important sentence in page-length passages. Again the bulk of the responses were on sentences that occurred first or early in the passage, then with another, smaller peak at the end of the passage. Finally, Kieras (Note 3, in press-b; Kieras & Bovair, Note 7) collected importance ratings for individual sentences in paragraphs in which the main idea was either explicitly presented in the first sentence, or was absent. When present, this initially presented main idea sentence was very heavily chosen as the most important sentence. However, with some passages, sentences appearing at the end were also considered fairly important, especially if the initial main idea sentence was missing.

These results suggest that the initial position in a passage is the most popular location for important information. However, a second location is the end of the passage. As suggested in Kieras (Note 3), some passages appear to have a structure consisting of an argument leading up to a conclusion.

The function of initial mention. The results summarized above, along with theoretical considerations (e.g., Carpenter & Just, 1977), suggest that the initial position in a passage is uniquely important. Serial position effects in prose recall have been observed (see Meyer, 1977), but these have usually been attributed to the fact that the important information tends to appear first; since important information is recalled better, then the first information will be recalled better than later information. However, the initial position could serve to mark information as important, making initially mentioned information thematically important to some extent just by virtue of its

position.

This hypothesis was confirmed by the studies reported in Kieras (1980), using the main idea and main item tasks. The approach was to keep passage content constant, and only vary what was marked as thematic by variations in order of mention. The results show that an item or idea is considered more thematically important if it is mentioned first than if mentioned later in the passage. Hence readers appear to expect the main idea or item to appear first in a passage, and so assign thematic importance to first-appearing items. Thematic effects produced by initial mention also appear in recall, and cannot be attributed to simple serial position effects (Kieras, 1981c).

Accompanying the thematic role of initial mention, there is also an important reading time effect of initial mention. The first sentence in a passage is usually read for a relatively long time. This has been demonstrated in two ways (see Kieras, Note 8, 1981b, in press-b; Kieras & Bovair, Note 7). The first is studies manipulating the presence or position of an explicit initial main idea sentence in using a sentence-at-a-time paradigm. The sentence that follows the explicit initial main idea sentence is either the second sentence in the passage if the initial main idea is present, or it is the first sentence if the main idea is absent or elsewhere. The reading time on this sentence is longer if it appears first than if it appears second. The second demonstration is that the first sentence is read longer than would be predicted from its propositional content and its length. That is, using either a statistical model for sentence reading times, or a simulation model that represents parsing, referential, and representational processes, the reading time on individual sentences can be predicted (see Kieras, 1981b, in preparation). Consistently, the first sentence in a passage is underpredicted by such variables; significantly better fits are obtained by including a variable that represents that a sentence occupies the first position. With the passages studied, the estimate thus obtained of the additional time required on the first sentence is about 1 to 2 seconds.

Hence, the first sentence of a passage appears to require more processing than one would expect based on its other properties. The model-based assessment rules out some of the simple explanations, such as the need to define many new referents in the first sentence. Rather, there seems to be a unique function of the first sentence, perhaps one of "setting the stage", or preparing the comprehension system to process a large body of information about a certain subject matter. If the first sentence actually contains the main idea, then this stage-setting function will be maximally successful.

A good example of the importance of a main idea appearing in the initial position is the results in Kieras (in press-b; Kieras & Bovair, Note 7). These were obtained using passages based on the generalization macro-rule presented in a sentence-at-a-time paradigm, and with main idea responses, reading times, importance

ratings, and think-aloud protocols being collected. In these passages, the main idea was a generalization, either explicitly stated in the initial position, or absent, and the body of the passage consisted of a series of instances of the generalization with some irrelevant information present as well. The instances were ordered along some dimension, such as in chronological order.

As mentioned above, these passages have a fairly simple macrostructure. But the initial appearance of the main idea can make a substantial difference in the processing that subjects do while reading through the passage. In brief, if an obvious candidate for the main idea appears first, then the reader need only adopt it, and then test it for adequacy while reading the remainder of the passage. If not, the reader must attempt to formulate a main idea while reading, and be prepared to re-formulate it whenever a poor fit is noticed. As a result, some sentences may appear important when first read, but then later turn out to be merely details or irrelevant. Thus, the initially presented explicit main idea "protects" the reader against the irrelevant material or alternative possible main ideas, and so simplifies arriving at a main idea.

Shallow Semantics

Macrostructure processing can apparently proceed largely on the basis of only limited, or shallow, knowledge of the semantics of the subject matter. Given the nature of the technical prose materials studied in this work, one would suspect that the typical college student would be completely bewildered by the subject matter, and so be forced to rely almost exclusively on surface level cues to the important content. However, subjects display a marked ability to comprehend the propositional structure of a passage at a shallow level, and then use this information to identify the important content. This level of comprehension actually corresponds very closely in concept to the process engaged in by a prose researcher of constructing a propositional representation of a passage. Such a representation has many useful properties, such as its connectivity structure, even though it does not represent the full semantic content of the passage.

Subjects appear to be able to use the shallow semantic information to identify the main content even when the surface-level markers are inconsistent, or when the content is quite unfamiliar. The basic support for this assertion are the following observations: (1) Surface-level markers do not dominate subjects' responses; semantic considerations often override the surface markers. For example, in Kieras (1980), initial mention influences the choice of main item, but usually about a third of the responses were not of the marked item. As one subject commented during debriefing, of course the topic should appear first, but sometimes the obvious topic was elsewhere! (2) Even in very unfamiliar material, subjects are fairly consistent in assigning importance ratings to strongly relevant and irrelevant sentences, even if they are fairly inconsistent in their main idea responses (Kieras, Note 3, in press-b; Kieras & Bovair, Note 7).

(3) Subjects can use some of the easily inferred semantic properties of sentence terms to relate an individual sentence to a main idea. For example, in an experiment using think-aloud protocol methods (Kieras, in press-b; Kieras & Bovair, Note 7), a subject read the sentence A hydrogen maser clock has pico-second accuracy for 10 million years in a passage about how modern timekeeping devices are extremely accurate, and commented, "I don't know what a hydrogen maser is, and I don't know what a pico-second is, but this is obviously a clock that is extremely accurate". (4) Subjects can use simple superordination relationships presented in a passage to choose main items, even when the terms are novel. For example, in Kieras (1980, 1981c), a passage was used in which biotransformation was described as a general process, and the liver was introduced as an organ that performs biotransformation, and then further described. Subjects showed a very strong tendency to prefer the general, but unfamiliar term, as the passage topic, even though propositions about the liver were much better recalled.

Thus, it appears that at least a major portion of macrostructure processing can go on without full or deep understanding of the passage content. Hence, the role of general knowledge in these tasks is relatively limited; when subjects can pick out central propositions using only superficial or simple semantic relations, more detailed knowledge is not necessary. Note that the college students used as subjects in this and most prose research probably have developed during their long history of schooling a specialized skill for dealing with complex verbal material without fully understanding it.

A Model of Thematic Processes

Thematic content is specified by a combination of information at different levels and of different types. Overall, it seems that the most important information source is the propositional structure of the passage content. In the discussion above of shallow semantics, it was pointed out how people can deal with complex technical prose material without full comprehension of it. Apparently they make use of the superficial characteristics of the semantics and the propositional structure.

That the propositional and semantic content of a passage would be the most important determinant of macrostructure is in the spirit of the original macrostructure theory. But a major modification of the theory is that surface level features, both of individual sentences, and the passage as a whole, also influence the macrostructure-building process. This is an important point. Ever since Sachs's (1967) paradigmatic study showing the apparent unimportance of surface form, the cognitive psychology of comprehension has tended to ignore surface structure in favor of semantic content. However, it seems clear that surface structure is normally chosen by the writer in an attempt to convey a desired meaning most efficiently. The reader is expecting these conventional uses of surface structure, and so bases his or her meaning interpretation on them to some extent. Hence an adequate

theory of comprehension must explain not only how readers derive the semantic content of sentences and relate them to already known information, but also how the surface form of the input is used to guide or streamline this process.

A model conforming to this theoretical approach is reported in Kieras (in press-b; Kieras & Bovair, Note 7), and will be briefly described here. Although the model is rather limited, having been applied only to the generalization passages described above, it does illustrate the principle that main ideas can be derived with only shallow semantic knowledge, and through the use of textual and sentence surface structure as well as the propositional content.

The model takes the propositionalized form of the passage as input, and processes it one sentence at a time. It sets up and maintains a hypothesized or candidate main idea for the passage, and may modify this in the course of processing the passage. The final candidate is then reported as the main idea. For simplicity, the model uses only a single proposition as its main idea, which is supposed to correspond to the main proposition of a subject's main idea response.

The model adopts a candidate main idea usually after reading the first sentence, and then tests each succeeding sentence for being an instance of the main idea generalization. If so, the model proceeds to the next sentence. But if not, the model may, depending on a decision rule, compute a new candidate main idea. Different rules for this decision to revise the main idea are possible. For example, a revision attempt is indicated if a large sentence that is unrelated to the current main idea is encountered, or the model has accumulated more propositions that are unrelated to the main idea than are related.

The model implements van Dijk's generalization macro-rule with rules for summarizing a set of specific propositions with a general one, basically by finding sets of propositions whose arguments are concepts that share supersets. Thus, the general knowledge required by the model is quite limited, consisting of little more than set-superset relations for the arguments. The fact that so little knowledge is required may explain much of the shallow semantics phenomena described above.

But detailed general knowledge seems to be quite important in the micro-level inferential process required before the macro-level processing can be applied. For example, the sentence The Hellenes used bronze swords can not be related to the main idea cultures use metals until an inference is made. The model performs this inference with a rule in general knowledge that if X uses Y, and Y is made of Z, then X uses Z. This rule yields Hellenes used bronze, which can be related to the main idea. Hence, before the macroprocesses can work, the micro-level elaboration and inferences must be done. Intuitively, such inferences should be driven by the current hypothesized main idea. But the model simply makes all inferences that its knowledge

allows before proceeding, a simple, but rather inefficient and unrealistic process.

The model relies heavily on the surface structure of the passage and the sentences in arriving at a main idea. At the sentence level, the model makes use of the main proposition in a sentence more than the others, because the main propositions are usually more relevant to the global main idea. The designation of a proposition as a main proposition is done on the basis of the sentence surface structure; it is the one representing the main verb relating the surface subject to the surface object.

The role of textual surface structure is very important in that the initial mention convention is a central part of the model's processes. If the model determines that the first sentence main proposition contains general terms, it concludes that the first sentence contains a candidate main idea, and so adopts the main proposition as its first main idea. It then selects a relatively conservative criterion for deciding when to revise the main idea on subsequent sentences. Thus, if a passage has an explicit first sentence main idea, the model adopts it, and will keep it unless it encounters a severe degree of inconsistent information in the remainder of the passage. This corresponds to the general result in Kieras (in press-b; Kieras & Bovair, Note 7) that the first sentence main idea is usually produced as the main idea response, with few revisions occurring along the way.

In contrast, if the first sentence is not general, the model either generalizes the first sentence to get a candidate main idea, or waits until the second sentence is processed, and then generates a main idea. These two strategies were observed in the think-aloud protocols reported in Kieras (in press-b; Kieras & Bovair, Note 7). The model then selects a liberal, or "hair-trigger," criterion for revising the main idea. Since the model had to "guess" a main idea, it must be prepared to abandon its initial guess quickly in favor of another. As observed in human readers, the result is that when the main idea is not explicitly stated, the model changes its mind relatively often.

Conclusion

The model represents the combination of the use of both surface and semantic information in arriving at a main idea. The surface information acts to guide the process by which the semantic content is used. In Kieras (in press-b; Kieras & Bovair, Note 7) more detail is provided on how the model conforms to human subjects in terms of reading times, importance ratings, and think-aloud protocols. While the model has some serious problems and limitations, its overall performance is encouraging. Hence the model performs its function of summarizing the major features of how people abstract main ideas from technical prose.

Reference Notes

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APPENDIX

Reports, Publications, and Presentations
Produced Under Contract N00014-78-C-0509, NR 157-423

Technical Reports

1. Kieras, D. E. The relation of topics and themes in naturally occurring technical paragraphs. Technical Report No. 1, University of Arizona, January, 1979. AD A065154.
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